LUBRICATION

A Technical Publication Devoted to the Selection and Use of Lubricants

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Aircraft Engine Lubrication

THE World War demonstrated the value of the airplane as an adjunct to military operations. Post-war developments based on military experience proved it to be a practicable means of transportation. All this, due to the intelligent organization of research:

The engine designer studying matters of fuel economy, strength of materials and engine dependability;

The structural expert investigating wing design and problems of stability;

The physicist, the problems of instrumentation to increase flying safety at night, in fogs and at high altitudes;

And the petroleum chemist, the refinement of fuels and lubricants to assure of proper functioning of the engine regardless of flying conditions.

So aviation passed from the romantic, sporting phase to the present-day stage of a virtual public utility. The day of haphazard flying had passed definitely when the late depression dawned. In its place today we have a well organized industry engaged in more improvement endeavor than almost any other. This has not been brought about alone by the comparative newness of this industry and the accompanying thought that therein lies more room for improvement than in older industries; it was perhaps fostered more actively by the desire of the sponsors of aviation to make the airplane and all its adjuncts a tribute to research coordination and an inspiration to engineers and designers in allied industries toward the production of better products.

The performance and reliability of the modern aircraft engine is absolutely astounding. In airline practice today engines operate for 20,000 miles between oil changes and 100,000 miles between overhauls. All this with a weight of but 1.3 pounds per horsepower and a power output of 0.6 horsepower per cubic inch of piston displacement.

As equally astounding has been the remark-

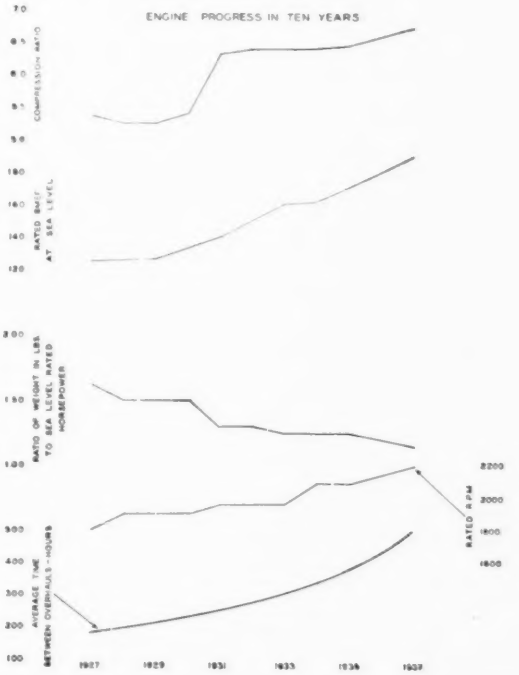


Fig. 1—Note increase in pressures, power, r.p.m., and overhaul time in contrast to decrease in weight/power ratio.

able increase in engine power output with but negligible dimensional change during the past few years. This increase has been brought about through the cooperation of the aviation and petroleum industries. In justice to the aviation industry it must be acknowledged that engine design preceded the availability of suitable fuels and lubricants for these perfected mechanisms. So the petroleum industry combined its entire research and refinery facilities in order to provide products which would make these modern super-engines commercially usable.

Power output increased due to the following factors:

1. Improved metallurgy.
2. Improved combustion chamber cooling.
3. Higher crankshaft rotational speeds made possible by the development of superior bearing metals.
4. Improved lubricating oils.
5. Better fuels facilitating higher compression ratios and greater supercharging.

As a result, the fuels and lubricants which were in use several years ago would be entirely inadequate to properly empower and safeguard today's giants of the airways. Lubricants have been given especial attention because of the high temperatures and pressures under which the oil must work, the need for elimination of carbon residue and gum accumulations, particularly around piston rings, and the nature of the bearing construction.

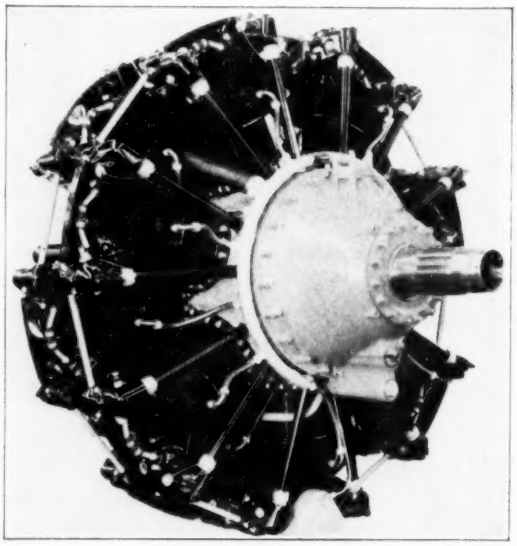
Due consideration of the problem involved in the maintenance of lubrication of the variety of bearing dimensions and locations has led to interesting applications of anti-friction bearings; these will usually operate well on a mist of oil whereas the sleeve type bearing often requires a flood of lubricant under pressure. As a matter of fact the anti-friction bearing is now quite generously applied to the entire plane structure from the nose and controls back to the tail wheel.

ENGINE DESIGN

The aircraft engine will differ in design and function from the automotive or marine type gasoline engine with which most of us are familiar. On the other hand, automobile engines are being installed in some light planes but this usage has scarcely passed the experimental stage. One of the major differences is the method of cooling. Practically all air craft engines in use today are air cooled. This will cover a range in power output from 36 to 1,500 horsepower. Their cylinder arrangement in turn can be either radial, in-line, or opposed with respect to the crankshaft.

Characteristics of the Radial Engine

The standard radial engines in use in commercial service today are practically all of either single row, nine-cylinder, or twin row, fourteen-cylinder arrangement. The most satisfactory radial engine from the standpoint of general performance and economical operation is that with sufficient optimum size cylinders to give the necessary power output. On the other hand, although lower initial cost results from employment of a minimum number of very large cylinders, the engine so constructed is likely to be rough, of excessive frontal area and of probable shorter life. It is for this reason that the engine of today which is capable of producing considerably more than one thousand horsepower employs the double row feature, as is expected in the engine of tomorrow which will step up this power output materially.



Courtesy Pratt & Whitney Aircraft Corp.

Fig. 2—Front view of 14 cylinder air cooled radial Twin Row Wasp aircraft engine. Note tubing between rocker arm boxes to circulate lubricant to these parts, also shielded ignition wiring which eliminates radio interference.

The cylinders on radial engines are equi-angularly spaced about the crankshaft throw. Due to the employment of but one crankshaft throw per row of cylinders it is necessary that the bearing on this throw be carried by one master rod which in turn is carried by one cylinder. By equi-angular spacing, it is possible to connect the remaining cylinders to the master rod by link rods. It is therefore apparent that an even number of link rods will be employed which, in addition to the one master rod, indicates why radial engines always employ an odd number of cylinders per row. This arrangement also permits even firing of the engine.

In-line Engine Design

Where six cylinders or less are required to obtain the necessary power, it is usual practice to build a straight in-line engine. When power requirements necessitate eight or more cylinders the Vee type is used at a slight sacrifice in frontal area.

Angles of from 45 to 180 degrees are usually employed in Vee engines, one crank throw being provided for each pair of cylinders. Inasmuch as the angle of the Vee controls the ultimate frontal area, it is advantageous from this viewpoint to reduce the Vee to the smallest angle which permits adequate room for all parts and maintenance thereof, as well as room for the circulation of sufficient cooling air, other considerations in choosing angle are balance and firing interval.

An interesting development in Vee engines is the high output 12-cylinder ethylene glycol cooled unit for military purposes. The use of ethylene glycol, which boils at a temperature of about 380 degrees Fahr., permits the use of a very small radiator for jacket liquid cooling purposes; the resultant overall drag of such a liquid cooled engine, coupled with the attendant reduction in radiator dimensions, renders such a combination quite comparable to the standard radial engine.

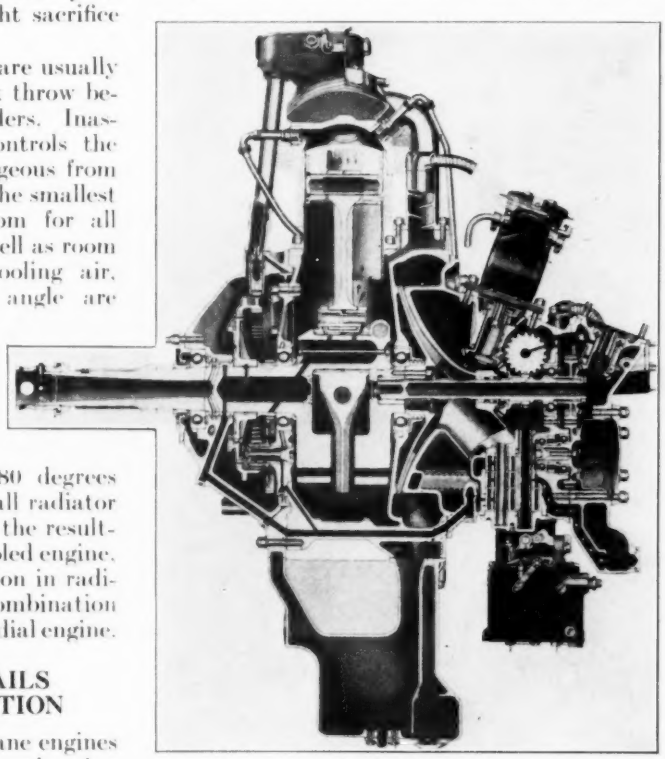
CONSTRUCTIONAL DETAILS PERTINENT TO LUBRICATION

Lubricating requirements of airplane engines can be best understood through comprehension of the principles of bearing construction. Both sleeve and anti-friction bearings are used, the former most generally in the in-line engine, the latter being best adapted to the radial engine. The lubricating principle of the in-line engine is very similar to the automotive engine, the outstanding difference being the dry sump system which maintains the main oil supply outside the crankcase proper.

Sleeve-Type Bearing Clearance

The essential lubrication problem in the sleeve-type bearing is the maintenance of a continuous oil film within the small clearance space regardless of fluctuation in operating temperatures. The range of these latter will usually be greater in aircraft engine service than automotive. This requires more clearance in most of the sleeve-type bearings involved. On the other hand, clearances will vary according to the bearing size and temperature range, although in general a clearance of 0.001 inch per inch of shaft diameter has been found to result in the maintenance of effective lubrication with the least amount of wear provided the lubricating oil is suited to the prevailing operating temperatures and pressures.

According to the unwritten requirement of the airplane engine, bearings must be as light as possible commensurate with strength requirements in order that weight may be kept to a minimum. This is one of the reasons why most shafts and pins are of hollow construction.



Courtesy of Aviation Manufacturing Corp. (Lycoming Division)

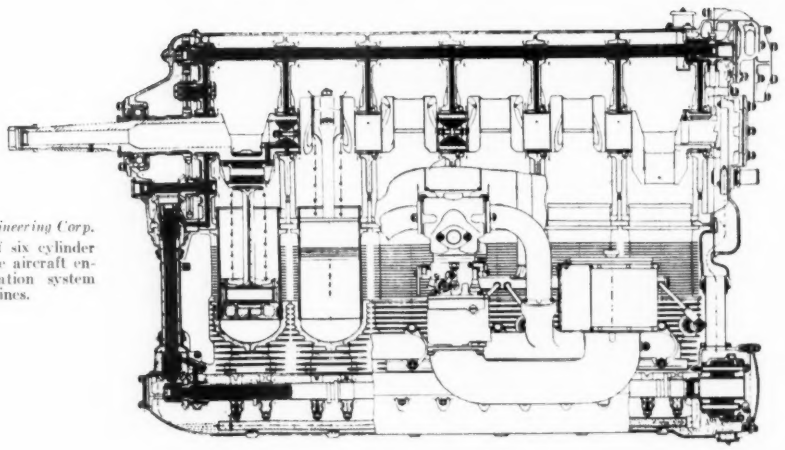
Fig. 3—Cutaway view of Lycoming aircraft engine, showing construction details. Note the use of two spark plugs per cylinder, each of which is fired by a separate magneto thus providing a considerable factor of safety.

Rate of Oil Circulation

In aircraft engines the lubricating oil must serve a dual purpose, functioning not only as a lubricant but also as a coolant. The rate of circulation, therefore, provides for a considerable excess over the amount required for lubrication alone. In the old Liberty engines it was necessary to circulate twelve gallons of oil per minute. In contrast, present-day engines of much greater power output achieve this dual purpose with an oil circulation rate of from five to ten gallons per minute. This of course indicates the progress in engine cooling which has taken place in recent years.

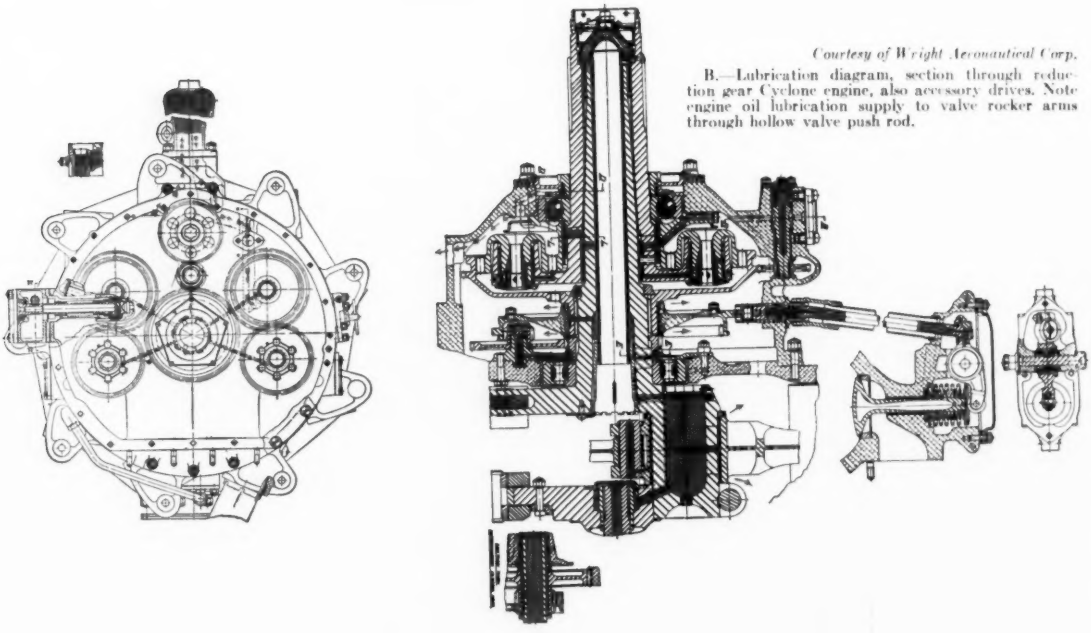
Plain Bearing Construction

Engine bearings in aircraft service will differ



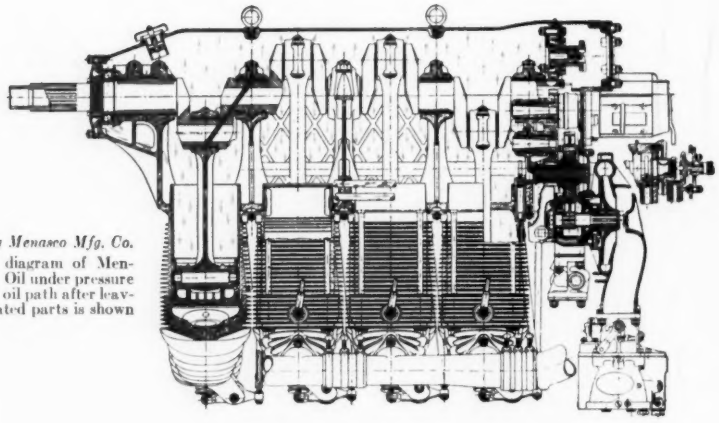
Courtesy of Ranger Engineering Corp.

A.—Cutaway view of six cylinder Ranger air-cooled in line aircraft engine. Pressure lubrication system shown in heavy black lines.



Courtesy of Wright Aeronautical Corp.

B.—Lubrication diagram, section through reduction gear Cyclone engine, also accessory drives. Note engine oil lubrication supply to valve rocker arms through hollow valve push rod.



Courtesy Menasco Mfg. Co.

C.—Lubrication diagram of Menasco Pirate engine. Oil under pressure is shown in red and oil path after leaving pressure lubricated parts is shown in green.

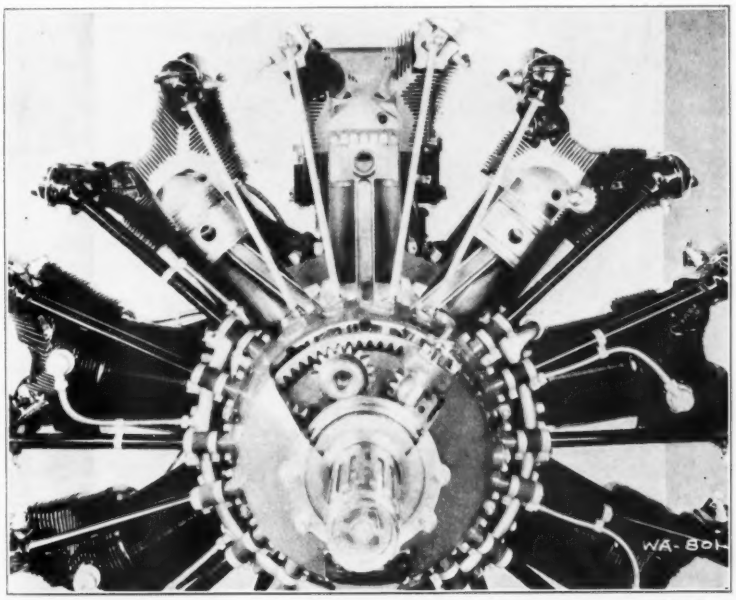
from the designs used in other types of machinery in that the bearings are seldom grooved to any extent. This practice has been adopted to save weight and space since the absence of grooving permits greater loads to be carried per unit of bearing diameter. Another consideration is the fact that absence of grooving enables higher oil pump pressures to be carried; at the same time with these higher pressures there is less need for grooves since distribution is maintained by the oil pressure at the points of delivery.

This latter can, of course, be varied according to the calculated working pressures encountered; it will also vary with the bearing temperatures. For example, on cold starting, the oil pressure will be comparatively high, but as the bearings warm up and oil viscosity is reduced to thereby facilitate more ready flow through the clearance spaces, the oil pressure will diminish to working value. Normal operating pressures average from 60 to 80 pounds per square inch.

OPERATING CONDITIONS

The conditions under which the average aircraft engine must function require:

1. Take-off and climb at nearly wide open throttle full speed.
2. Normal or cruising operation at much greater throttle or percent rated power output than is usual in automotive service.
3. Considerably higher mean effective pressures than are encountered in automotive service.
4. The ability to function faultlessly under a wide variety of atmospheric temperatures and weather conditions.
5. Maintenance of lubrication according to the dry sump principle, whereby two oil pumps are employed; one for circulation of oil to the engine, and the other for scavenging excess oil from the sump and transferring it to the main oil tank.
6. Operation at the most economical air-fuel ratio since the cruising fuel consumption limits the distance covered and the amount of pay load carried in transport operation.



Courtesy of Wright Aeronautical Corp.

Fig. 4—Cutaway of Cyclone engine front showing reduction gears, valve push rods, cylinder and piston construction. Note the depth of the cooling fins on cylinders and pistons.

Throttle Requirements

The extent to which the throttle is open will, of course, have an effect on fuel consumption since the average cylinder temperature is the limiting factor in fuel economy in aircraft engines. Cylinder temperature in any given design depends on power output, the leanness of the air-fuel mixture, and the rate of coolant circulation. For these reasons it is usual practice to operate at full rich air-fuel ratio during take off and climb; as the throttle is eased off to cruising power the air-fuel ratio is leaned to that point which practice indicates will give the best combination of fuel economy and cylinder temperature.

Advantages of Dry Sump Lubrication

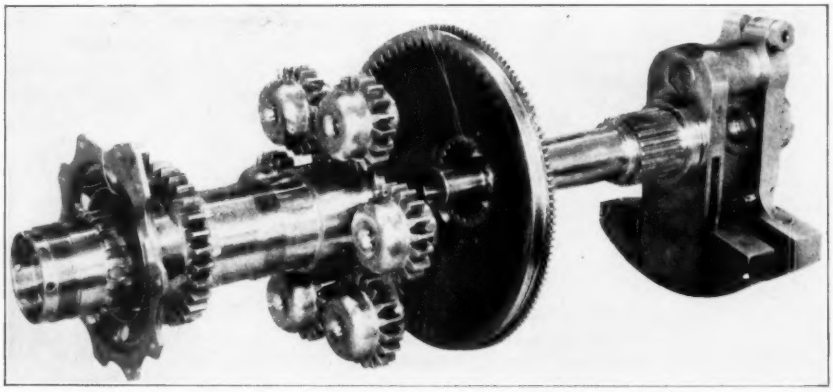
Full pressure lubrication is applied to virtually every part of the aircraft engine with the possible exception of ball bearings, cylinders and wrist pins on some designs. Regardless of the extent, rate or manner of oil circulation, however, practically all aircraft engines are designed to operate with a dry sump to enable flying at any angle without effect upon the oil supply.

There are certain distinct advantages pertaining to dry sump lubrication, viz.:

1. More complete oil cooling is afforded prior to each recirculation by means of an external tank and radiator. The oil can, therefore, be readily maintained within the proper

viscosity range before being again subjected to service.

2. Flooding of some cylinders with simultaneous starving of others is more effectively prevented when angle or inverted flight occurs.



Courtesy of Wright Aeronautical Corp.

Fig. 5—Cyclone aircraft engine crankshaft, propeller shaft and reduction gear assembly. Note in particular the size of the reduction gearing which transmits the full engine power.

VALVE GEAR LUBRICATION

Nearly all aircraft engines are designed to take advantage of the slightly greater power obtainable from over-head valve arrangement. This necessitates separate lubrication for the rocker arms. In some radial and most in-line engines this system is connected directly to the engine oiling system. In contrast, however, there are a few radial engines which are designed for grease or very heavy oil-lubrication of the rocker arms by means of the conventional pressure grease gun and fittings. Pressure gun lubrication of the valve gear is usually required every five to eight hours of engine operation.

The marked reduction in wear of the valve stems and push rod ball ends when continuous lubrication is employed is attributed to the more automatic way in which fluid lubricant is circulated by the engine oiling system. This reduction in wear as well as the relief from necessity for frequent use of the hand pressure gun has led many operators to change over to engine oil pressure lubrication by means of an easily installed adaptation. The changeover is made by mounting a worm driven piston type lubricator on any of the engine accessory drives. The length of piston stroke is adjustable so that the amount of lubricant can be nicely controlled between insufficient supply with resultant excessive wear, and over supply with resultant smoky exhaust and spark plug fouling. Oil is metered from the lubricator to the rocker arm box of No. 1 cylinder and thence into a series of flexible tubes designed to withstand heat, oil and vibration.

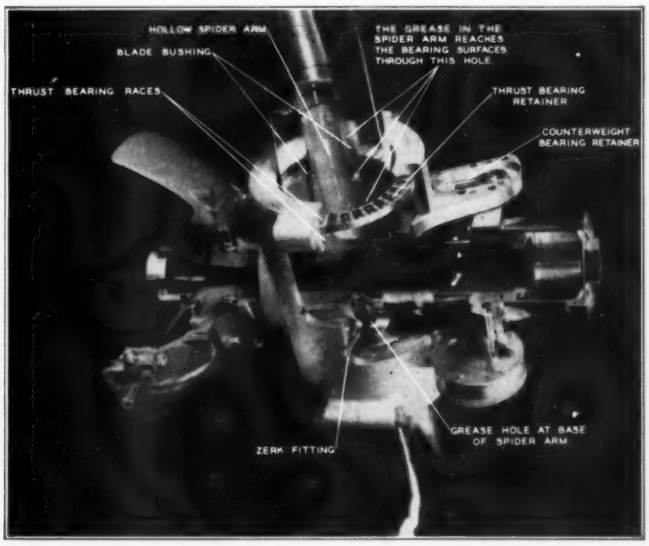
These connect in a complete, continuous circuit to fittings at the ends of the rocker arm bearing bolts, which are drilled to provide for the passage of oil from one rocker box to the next. Through this drilled passage a supply of oil is forced into the rocker arm bearing and flows out into the rocker box where it is utilized to lubricate the valve stem, rocker roller and push rod ends.

In some designs no lubricating oil from such a system is returned to the engine oil supply, but since the quantity metered is approximately one drop per second, the main oil supply cannot be lost in the event of breakage or damage to the external tubing. In other designs excess lubricant is returned to the main oil supply by passing through the push rod covers to the crankcase, where it is picked up by the scavenging pump.

REDUCTION GEARS

The modern airplane engine obtains its maximum horsepower at speeds in the region of 2,200-2,600 r.p.m. Since the efficiency of air propulsion increases with propeller size and decreases with increase in propeller tip speed it is desirable to use large, low speed propellers for absorption of high powers. In order that the propeller may fulfill these requirements it is customary in the larger engines to employ reduction gearing for the purpose. Needless to say, this gearing must be contained within the engine; it is necessarily located between the crankshaft proper and the propeller, and must therefore be of small diameter in order that it will not interfere with cylinder cooling at the same time the allowable tooth width is strictly limited both from a weight and space consideration.

The solution of this problem is a triumph of metallurgy and designing skill when one considers that these relatively small gears transmit at about 99 per cent efficiency many hundreds of horsepower and are lubricated by the same oil that lubricates the rest of the engine. The tooth pressures and rate of pressure rise during acceleration are considerably in excess of normal design practice. The reason these gears stand up is due to the materials used, their accurate machining to a fine surface finish, the rigid alignment and mounting, and the way in which they are kept continually supplied with cool lubricating oil.


HOLLOW SPIDER ARM
BLADE BUSHING
THRUST BEARING RACES
THE GREASE IN THE SPIDER ARM REACHES THE BEARING SURFACES THROUGH THIS HOLE
THRUST BEARING RETAINER
COUNTERWEIGHT BEARING RETAINER
GREASE HOLE AT BASE OF SPIDER ARM
ZERK FITTING

Courtesy of Hamilton Standard Propellers

Fig. 6—Sectional view of controllable pitch propeller showing blade thrust bearings and counterweight bearings. These bearings do not move appreciably and thus cannot be used to replenish their lubricant supply by their own motion.

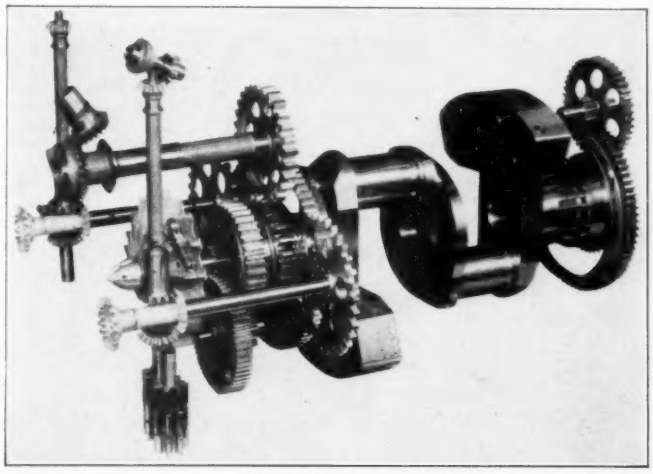
PROPELLERS

Since the propulsive force obtainable from a given propeller at a given speed is dependent on air density it is apparent that as the altitude of flight is increased and the corresponding air density decreases, less propulsive force will be obtained at any propeller speed. Prior to the introduction of the variable pitch propeller it was necessary to design the fixed pitch propeller to absorb full engine power at rated engine speed at the altitude commonly used. At ground level, therefore, in the more dense air, the propeller would hold the engine speed down to about 80 per cent of rated r.p.m., and consequently only 80 per cent of rated full power was available for take off. This deficiency severely limited the load carrying capacity of planes.

This loss in available engine power is avoided by the use of a controllable pitch propeller. With this mechanism the pitch or "bite" of the blades can be adjusted while in motion to permit the engine to develop rated speed and power during take off, climb and at the cruising altitude.

In the accompanying illustration, the engine oil pressure is used to shift the blades to the low pitch or take off position. In changing to high pitch or cruising position, release of oil pressure allows the centrifugal counterweights to come into action and shift the blades.

Strange as it may seem to those unfamiliar with aircraft lubrication problems, the controllable pitch propeller is the most difficult part of the power plant assembly to lubricate. Although the propeller is fixed on the crankshaft and does not move as a whole in relation to this shaft, the pitch changing mechanism and the propeller blades make small changes in position in relation to the rest of the propeller each time the blade pitch is changed. Inasmuch as the propeller is revolving at considerable speed it is necessary in most designs of controllable pitch propellers to provide lubrication by means of a very viscous lubricant, usually a grease, which is capable of resisting removal



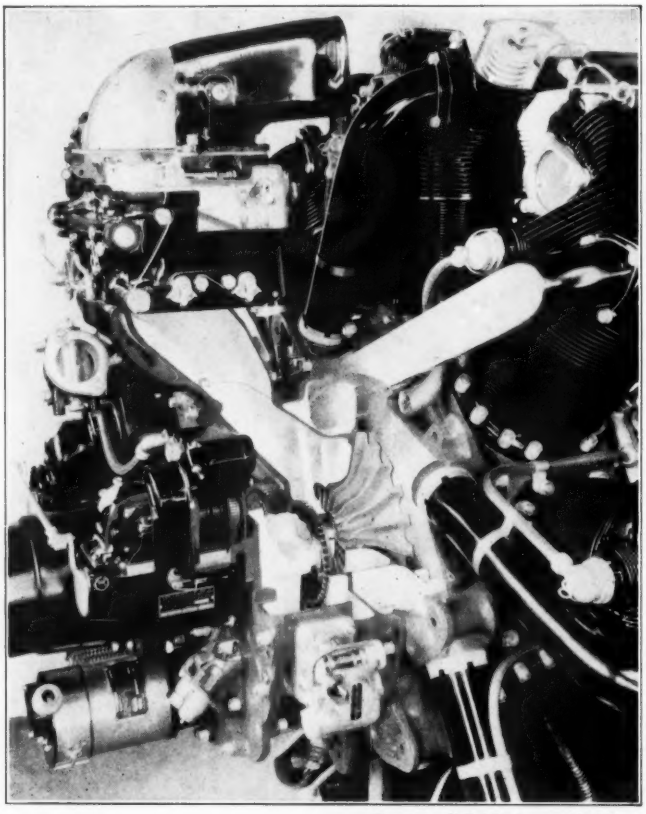
Courtesy of Pratt & Whitney Aircraft Company

Fig. 7—Crankshaft and drive gear assembly of Twin Row Wasp engine. Note in particular drives at left to supercharger, magnetos, oil pump, tachometer, gun synchronizers, starter, generator, etc. Also double throw crankshaft necessitated by employment of double row feature.

by centrifugal force; in addition, it must also withstand the torsional vibration of the crankshaft system as well as the vibrations inherent in the propeller itself.

The combination of these vibrations and the fact that the lubricated parts move but slightly produces a serious lubrication problem in that vibration corrosion wear and molecular transfer of metals occurs. The mechanism of these phenomena is not completely understood, but it is thought to be caused by the vibration forces and slight movement of the lubricated parts removing the lubricant from the bearing surfaces and thus permitting exposure to the air. Oxidation of the steel surfaces in the form of rusting, and molecular transfer of metals, can thus occur, although the rusted surface is removed whenever there is any movement, leaving what appears to be a scored, worn surface.

Some types of heavy greases, when used under such conditions, are apparently too viscous to maintain contact with the bearing surfaces, resulting in admission of air. It is thus evident that a less viscous lubricant would better serve to prevent this air entry; the fact that it might not resist throw-off by centrifugal force requires somewhat of a compromise in the final decision as how to best meet the requirements.



Courtesy of Wright Aeronautical Corp.

Fig. 8—Cutaway of Cyclone engine rear showing supercharger impeller and passages to and from impeller. Note employment of two magnetos, also shape of supercharger impeller.

THE SUPERCHARGER

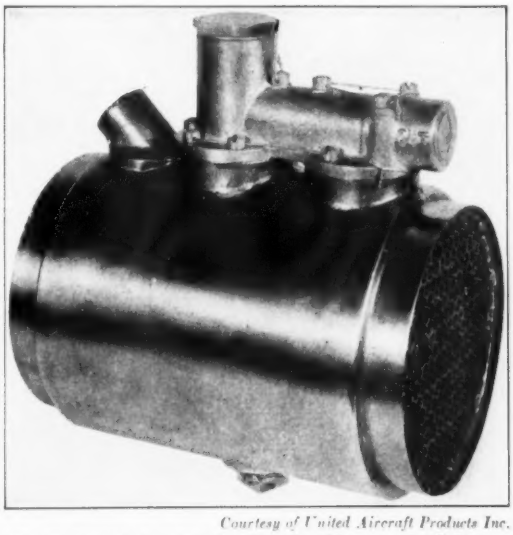
The majority of the larger aircraft engines employ a supercharger. Since the amount of power obtained per power stroke in a given engine depends primarily on the weight of the air-fuel mixture contained in the combustion chamber, it will be realized that in an ordinary engine the power obtainable decreases with decrease in air density or increase in altitude. The supercharger was originally developed to overcome this shortcoming in order that engines could develop their rated power at considerable altitude.

As improvements in metallurgy and petroleum refining technique made available respectively cylinders capable of withstanding higher pressures and fuels capable of combustion without detonation at these higher pressures, it became evident that supercharging could be employed to considerably increase the power output of aircraft engines at ground level during take off. Present day engines of the type used in transport service and fast private planes employ superchargers which, at ground level, create a positive absolute pressure equivalent to 35 to 45 inches of mercury in the intake system at full throttle, as compared to the considerable intake system vacuum existing in unsupercharged automotive engines at full throttle.

The high combustion pressures created by this supercharging and the high compression ratios used in large aircraft engines point to the reason why ordinary oils are not satisfactory for aircraft use. High combustion pressure results in high piston side pressure making the work of the lubricating oil doubly difficult since the higher side pressures increase the piston friction to result in increased heat generation and reduced lubricant viscosity. Airplane oils must therefore be capable of withstanding greater pressure without loss of lubricating value than ordinary industrial and automotive lubricants. In addition, due to the higher temperature conditions under which they must operate, the viscosities are higher than those used in other types of engines. Depending on the atmospheric and engine condi-

tions it is usual practice to operate large aircraft engines on lubricants within a viscosity range of from 100 to 140 Saybolt Universal seconds at 210 degrees Fahr.

The supercharger is usually driven from the crankshaft by step-up gearing. Ratios commonly used range from 4 to 1 to 14 to 1, depending on the size of supercharger impeller used and the cruising altitude at which it is desired to maintain rated power output. The approach of stratosphere flight is lending consideration to the employment of a dual ratio supercharger which can be shifted to a considerably higher driving ratio at stratosphere altitudes. It will be noticed that we therefore have in a supercharger what amounts to a centrifugal air pump which operates at tremendous rotational speeds in excess of 20,000 revolutions per minute. The entire assembly is of course balanced with the utmost precision; for this reason it is usually mounted on ball bearings.



Courtesy of United Aircraft Products Inc.

Fig. 9—Typical aircraft engine oil cooler of honeycomb cellular construction.

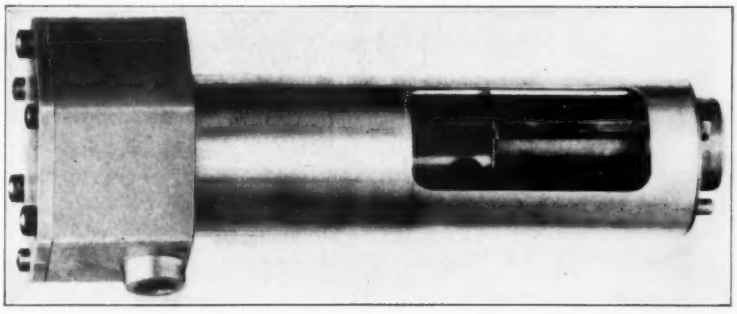
OIL COOLING

Two oil pumps are used in most aircraft engines, viz.: the pressure pump, which takes suction from the storage tank and applies oil under about 80 pounds pressure to the lubricated surfaces; and the scavenging pump which removes the oil as it drains from these surfaces to the sump. This pump generally passes the return oil through a cooler and thence back to the oil tank.

Oil must provide a great deal of piston cooling in aircraft engines in order to keep piston temperatures within reason. The extent to which the lubricating oil acts as a heat transfer medium is not generally realized. Consider for a moment the path of a quantity of oil in its cycle and the temperatures attained—according to one authority on the subject.

If it is assumed that oil enters the pressure pump at 150 degrees Fahr., it will reach a temperature of about 250 degrees Fahr., in its passage through the bearings. Part of this oil as it leaves the bearings will throw onto the cylinders, which in an average air-cooled engine will have temperatures of around 250 degrees Fahr., at the base and 400 degrees Fahr., at the upper portion. Some of the oil is also thrown against the underside of the piston heads, which reach temperatures in excess of 600 degrees Fahr., during severe operation. The oil draining from the pistons and cylinder walls is at a temperature of about 450 degrees Fahr. This oil, draining to the crankcase, which is at about 250 degrees Fahr., mixes with oil drained from cooler parts of the engine and reaches the oil cooler at a temperature of from 250 degrees Fahr., to 300 degrees Fahr. A typical oil cooler for use on a 1,000 horsepower engine is capable of removing 1,400 B.T.U.'s per minute from the lubricating oil at an air speed of 160 m.p.h.

As in many mechanisms, the viscosity of the lubricating oil must be controlled at the operating temperature, or for a given oil the temperature must be controlled, in order to produce a safe viscosity. Since the strength of bearing materials and the resistance of lubricating oils to deterioration both decrease with increased temperature, engine designers and installation engineers try to keep the lubricating oil at a reasonably moderate temperature in order to safeguard both the oil and the bearings.



Courtesy of Cuno Engineering Corp.

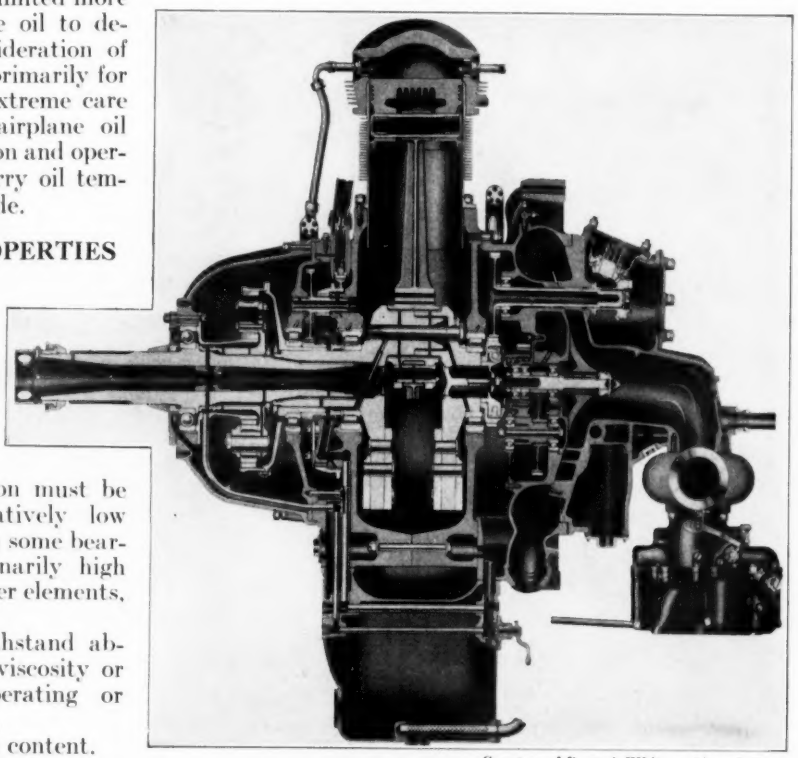
Fig. 10—Self cleaning oil filter of the rotating disk type. This element is not of the usual external type but fits into a cavity in the engine proper.

Severe oil deterioration frequently results in piston ring sticking. Stuck rings result in excessive oil consumption, increased blowby, further oil deterioration and eventually may end up with scored cylinders and engine failure. Therefore, the maximum allowable oil temperature is in some engines limited more by the tendency of the oil to deteriorate than by consideration of bearing strength. It is primarily for this reason that such extreme care must be exercised in airplane oil selection if the installation and operation are such as to carry oil temperatures on the high side.

AIRPLANE OIL PROPERTIES

Because of the service requirements which an airplane oil must meet, it is advisable to study those distinctive characteristics which an oil should possess. In this regard, due consideration must be given to the comparatively low clearances which exist in some bearings and the extraordinarily high speeds of the supercharger elements, in addition to:

1. The ability to withstand abnormal change in viscosity or fluidity under operating or starting conditions.
2. The carbon residue content.
3. The tendency to develop gum or resins which may clog the lubricating system, impair the free movement of piston rings and retard oil circulation.
4. Low pour test which will preclude possibility of congealment in cold starting.



Courtesy of Pratt & Whitney Aircraft Corp.

Fig. 11—Sectional view of Wasp geared aircraft engine. Note the extremely short piston and the employment of an oil control piston ring below the wrist pin.

Oil Stability

There are several effects of oil instability:

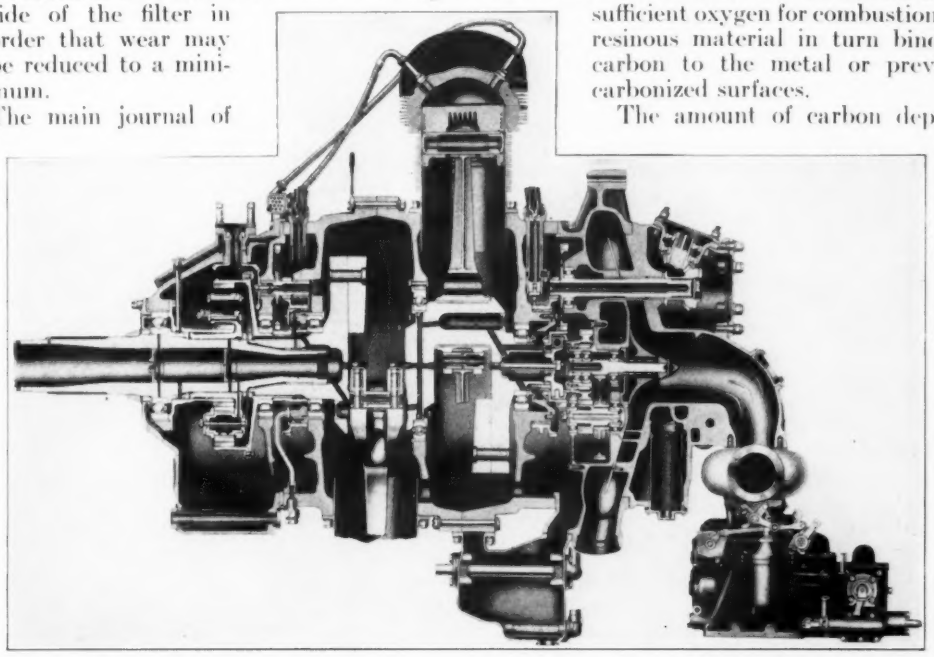
1. A gummy, sticky material deposits in piston ring grooves, piston skirts, under piston heads and on exhaust valve guides and stems. This material soon bakes into a hard varnish which sticks piston rings and exhaust valves and causes piston over-heating, which as previously mentioned may result in engine failure. Exhaust valve sticking can, of course, not be tolerated since it seriously reduces power output and increases engine roughness and vibration due to the unbalance created by one or more idle cylinders.
2. Small oil lines and channels may become so clogged up that the flow of lubricant will be seriously restricted.

In addition to the oil deterioration products which are often present in the lubricating oil, solid products of combustion in the form of fine carbon particles, and lead compounds resulting from reaction of tetraethyl lead anti-knock compound are often present in measurable quantities in the lubricating oil. Three means are frequently used to remove these materials and oil deterioration products from the lubricating oil:

1. A fine mesh screen of large area is placed in the sump so that the scavenging pump takes suction through the screen.
2. An edge filtration filter of the type shown is placed on the discharge side of the main oil pump. This type of filter is arranged with alternately rotable and fixed discs with about .005 inch spacing. The rotatable discs are usually turned by hand every five hours of operation to remove any material clinging to the exterior, which then falls off into a cavity not exposed to oil circulation. The filter shown is entirely automatic in that the movable discs are continuously turned at a rate of

about 2 r.p.m. by a small self-contained oil motor. The motor is driven by the oil pressure of the main oil pump; oil for its lubrication is taken from the discharge side of the filter in order that wear may be reduced to a minimum.

3. The main journal of the crankshaft, being hollow and full of oil, acts as a centrifuge to remove some of the undesired materials. This crankshaft cavity is easily cleaned on disassembly by removal of a plug.



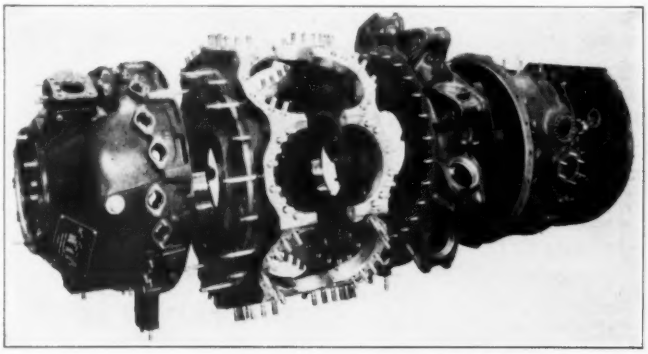
Courtesy of Pratt & Whitney Aircraft Corp.

Fig. 12—Sectional view Twin Wasp engine. Note profuse use of anti-friction bearings, also oil passages through double throw crankshaft.

Carbon Deposits

Aircraft engines operate at such high compression pressures that substantial reduction of clearance volume and increase in compression pressure by reason of excessive carbon deposits in the combustion chamber might be a dangerous condition. The way in which carbon deposits are understood to occur is of interest. If any engine, with cylinder heads removed, is rotated at a speed of 1,000 r.p.m. or more, a fine spray of oil can be seen to emerge from the cylinder tops. This spray action undoubtedly occurs when the cylinder heads are in place during normal operation as evidenced by the fairly uniform carbon coating usually found on piston heads. Some of the oil thus sprayed is in the atomized form, but the larger part is in the form of droplets which are exposed to flame during the combustion process. The atomized oil and the outer portion of each droplet will burn completely, but the central liquid portion will break down to form resinous and carbonaceous materials in the absence of sufficient oxygen for combustion. This resinous material in turn binds the carbon to the metal or previously carbonized surfaces.

The amount of carbon deposited by any oil, therefore, according to this theory, would depend upon the volatility of the oil at the flame temperature prevailing in the combustion chamber. In other words, the more an oil forms vapor, the fewer droplets are available to breakdown into carbon deposit.



Courtesy of Wright Aeronautical Corp.

Fig. 13—Main housing sections of a Cyclone radial engine. From left to right there are—nose, two power section halves, supercharger section, accessory section, and rear case.

SELECTION OF ENGINE OILS

The service to which an airplane oil is sub-

jected is so severe in modern high output engines that ordinary inspection tests such as flash, fire, viscosity index, etc., cannot reliably predict the ultimate performance of the oil in the engine. In lieu of oil specifications one prominent manufacturer of high output engines has set up the following full scale engine test to determine not only the suitability of oil for engines but the validity of oil improvements as indicated by laboratory tests. In order to keep the oil tests within reasonable cost they are made in conjunction with engine tests.

Before any engine test is made on an oil it must first pass an oxidation and bearing test; these serve as a rough guide as to oil stability and load carrying capacity.

The engine test consists of:

1. At least 50 hours at 0.40 h.p. per cu. in. displacement, which conditions are so severe as to exceed the worst conditions anticipated in flight service.
2. Oil-in temperature to engine should not be less than 185 degrees Fahr.
3. Oil temperature rise through engine shall not be less than 5 degrees Fahr.

Evaluation of the oil performance in this test is determined by an analysis of three factors:

1. Condition of the engine after the test.
2. Condition of the oil during and after the test.
3. Severity of operating conditions.

The analysis of these three factors is reduced to arithmetical terms. Engine inspection data are given twice as much weight as the used oil data. The two in sum are then qualified by the test conditions as indicated by the horsepower per cubic inch, average oil-in temperature and the average oil temperature rise. This arithmetical expression, which is thus reduced to a finite number, is known as the point score and expresses the performance of the oil as compared to a standard or any other oil similarly tested.

The changes of principal importance brought about by the use of oil in an aircraft engine include formation of sludge and asphaltenes, and increase in viscosity and acidity. Experience indicates certain sludge and asphaltene formation to be normal in good oils as follows:

	15 Hours Use	50 Hours
Sludge, mg./10 g.	62	305
Asphaltenes mg./10 g	20	75

These values are obtained by testing samples of used oil at 5 hour intervals and totaling the quantity of sludge or asphaltenes secured from three samples for 15 hours or 10 samples for 50 hours. These values are then divided into the product of the values shown in the tabulation above by 100. For instance, if the sum of the first three 5-hour samples in regard to sludge is 100, then that particular score becomes

$$\frac{62 \times 100}{100} = 62 \text{ sludge value.}$$

The average of these four sludge and asphaltene scores become the sludge and asphaltene score.

One point is deducted from the oil score for each 5 sec. increase in 210 degrees Fahr., viscosity above the first 10 sec. increase from the new oil value after 50 hours use.

One point is deducted from the oil score for each 0.10 increase in neutralization number above 0.10.

Engine Inspection

The inspection of the engine at the conclusion of the oil test indicates some very significant information on the lubricating qualities of the oil used, providing of course that the observer is qualified to make such an inspection by a suitable background of experience in the appearance and characteristics of the type engine used. In order that this information may be systematic, the parts and condition of the engine are listed with a value assigned to each part, weighted by its importance in the proper functioning of the engine. The sum of these values becomes the engine inspection score, which is 100 if perfect.

Part	Score
Piston wear and appearance	5
Piston pin loss wear	1
Appearance piston thrust surface	4
Piston ring wear	20
Piston ring sticking	5
Piston ring feather	5
Cylinder barrel wear and appearance	10
Piston pin wear	1
Link pin wear and appearance	4
Link pin bushing wear and appearance	1
Piston pin eye wear and appearance	1
Master rod bearing wear and appearance	14
Spider bushing wear and appearance	3
Master rod journal wear	8
Crankcase cleanliness	6
Crankcase sludge	5
Master rod cavity sludge	2
Filter	5
	100

The results of the oil inspection and engine inspection are then modified by the factor calculated by the engine operating conditions to obtain the final figure of merit.

This system is a praiseworthy move to afford the lubricant manufacturer a yard-stick for use in his constant efforts to improve the performance of airplane oils.

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